V–04.01 General

This Section is intended to provide a guide for the selection of drainage structures that are designed to convey a discharge of 500 cubic feet per second (cfs) or less based on a flood frequency of 25 years.

Generally these structures don't need a complete Hydraulic Report, as for bridges, as outlined in Section V–02.

The function of a culvert is to carry surface water across or from the highway right-of-way. In addition to this hydraulic function, it must also be able to withstand construction and highway loads passing over it. This Section will only deal with the hydraulic features. The structural features are covered in the Standard Drawings.

The designer should consult AASHTO'S, "Highway Drainage Guidelines" (1992 or the latest revision) as a reference.

V–04.02 General Policies

The following general policies should be used by the designer when designing small highway structures:

- The minimum diameter of pipe for centerline should be 24 in. The maximum length of this diameter pipe should be 100 feet including end sections. If more length is needed a 30 in. diameter pipe should be used.

- The minimum diameter of pipe for approaches should be 18 in. Some Districts are requiring a 24 in. diameter as a minimum. The maximum length of these diameter pipe should be 75 feet. If more length is needed a larger diameter pipe should be used.

- Reinforced Concrete Pipe should be used for centerline except when the diameter exceeds 84 in. In this case the type of culvert used should be based on a cost comparison.

- For all state highways, conduit pipe should be specified for approaches. Permissible options are Reinforced Concrete (RCP), Corrugated Steel (CSP), Corrugated Aluminum (CAP), and Plastic.

- End Sections should be used on all pipe except for pipe that are skewed more than 30 degrees.

- Multiple pipe installations should have a minimum space of 1.5 feet between the flared end sections.

- The minimum earth cover over culverts, measured at the shoulder, should be one (1) foot.

- Where practicable, all drainage structures should be extended so that the open portion of the end section is beyond the clear zone for the respective highway classifications, but should be a minimum of 84 foot in length.

- Where practicable, all drainage structures should be designed so as not to exceed an outlet velocity of 10 feet per second. If this is not possible, some form of outlet erosion control should be provided.

- Where practicable, the maximum allowable headwater elevation for each pipe should be set at the graded shoulder elevation, or a maximum height of two pipe diameters, measured from the invert at the outlet end of the pipe. Each pipe should be evaluated for an acceptable tolerance for flooding. See Par.V–04.04 and Appendix V–01A.

- 100 year flood data is required on all drainage structures larger than the minimum size. This applies only to centerline pipe.

- All Reinforced Concrete Pipe Sections should be tied.

- Changes in the existing drainage should not be made without approval of the respective Water Resource District.

V–04.03 Determination of Drainage Areas

The following procedures should be used in determining the drainage area:

- Drainage areas should be outlined on county maps, aerial photographs, U.S. Geological Survey Contour Maps, or specially prepared maps.

- All drainage area boundaries should be followed from the highway centerline, surrounding the area being covered, and closing again at the centerline. If there are any exceptions to this it should be noted on the map. These notations should show location, and if possible, elevation of break-over or diversion to or from the drainage area.

- If practicable, the drainage area should be closed for each existing culvert along the project and for each probable cross drain location.

- In cases where two or more structures operate together to drain an area, this information should be noted.

- When the drainage area has been plotted, the acreage should be computed.

- In locations where accurate definition of the drainage areas from maps is difficult, the map information should be supplemented with a survey, or there should be a field review of the project to verify the drainage area. Ditch Blocks and approaches with side pipe should be noted and the top elevations specified.

V-04.04 Upstream Development

All stream crossings should be in compliance with the local flood plain regulations and, when identified, regulatory flood way requirements.

In those cases where a crossing is being replaced and upstream development includes buildings, the stream crossing should not increase the likelihood of impacts to those upstream buildings from that which existed with the original crossing.

In those cases where existing buildings are located upstream of a newly constructed roadway, the crossing should be constructed to pass a 100 year event without impacting those buildings.

V–04.05 Allowable Headwater

In determining the maximum allowable headwater, the designer should compare the alignment, the profile, and the cross section sheets to obtain the allowable headwater for the drainage crossing.

Usually the designer decides how high above the inlet elevation of the culvert the water may go without causing damage to adjacent property, and without overtopping the highway.

Potential damage to adjacent property or inconvenience to the owners should be of primary concern.

The allowable headwater should be compared to the elevation of the watershed's natural divides. It is often necessary to construct ditch blocks so a selected culvert may operate efficiently and to prevent flow from one drainage area to another.

The following parameters have been developed to provide the designer general guidelines for designing pipes for areas up to 1000 acres. Headwater depths for pipes will not generally exceed the values listed below:

Maximum Allowable Headwater

Pipe Size	Allowable Headwater*	Slope (feet/mile)	Topography/ Land Use
24" - 36"	pipe diameter + 1 foot	1 to 5	Flat / Cropland
42" - 54"	pipe diameter + 2 feet		
60" -84"	1.5 pipe diameters		
24" - 36"	pipe diameter + 2 feet	6 to 10	Moderate
42" - 54"	1.5 pipe diameters		
60" -84"	2 pipe diameters		
24" - 84"	2 pipe diameters	>10	Rolling to Steep

* The allowable headwater will be site specific. These guidelines may vary based on sound engineering judgment, and with the approval of the Hydraulics Engineer in the Design Division. Pipe diameters are measured from the flow line of the inlet end of the pipe. For multiple pipe installations, the allowable headwater shall be measured from the invert of the lowest pipe.

Where practicable, the maximum allowable headwater elevation for each pipe should be set at the graded shoulder elevation.

For arch pipes, the maximum allowable headwater shall be based on the rise of the pipe, and the pipe size category will be the equivalent round pipe size.

The maximum allowable headwater must also meet FEMA or flood hazard requirements. A Flood Plain Development Permit is required from the local Flood Plain Coordinator. The State Water Commission has a list of the local Flood Plain Coordinators.

V–04.06 100 Year Frequency

The 100 Year Frequency discharge and stage elevation data are required for all drainage structures greater than the minimum size diameter as shown under General Policies V-04.2. This information is required on federally funded projects and should be shown on the plans.

The design headwater elevation can be determined from the computer programs based on hydraulic fundamentals of HEC 5 &10.

This headwater depth plus the elevation of the structure at the inlet will give the 100 year high water stage elevation. If this elevation is greater than the roadway, the stage elevation must be adjusted downward to account for the flow over the roadway.

The flow over the roadway can be calculated by using the Weir Formula, $Q= kCLH^{3/2}$, where :

Q is the discharge in cubic feet per second.
C is an empirical coefficient for broad crested weirs
L is the length of the weir in feet.
H is the head in feet.
k is a coefficient

If the weir section is flat as in the case of a ditch block, k = 1.0

It is assumed, as a result of a 100-year flood, small drainage structures will probably be operating under full flow conditions. Therefore, the outlet velocity can be calculated by dividing the 100 year discharge by the full area of the culvert.

V–04.07 Determination of Peak– Flow Frequency

The method used by the NDDOT for determining the Peak– Flow Frequency is found in the USGS publication,“Techniques For Estimating Peak–Flow Frequency Relations For North Dakota Streams”. (Report 92–4020)

V–04.08 Selection of Drainage Structure

The NDDOT uses computer programs to determine the size of structures needed for the respective drainage area. The programs are based on the hydraulic fundamentals in HEC 5and 10. Contact the Hydraulics Sections in Design for these programs.

V–04.09 Determination of Outlet Velocity

The outlet velocity of culverts is the velocity at the downstream end of the culvert and it is usually higher than the maximum natural stream velocity. Depending on the value of the velocity it could result in erosion of the channel for a short distance downstream which in turn could impact the performance of the drainage structure.

When a culvert operates with inlet control, the outlet velocity is approximated by assuming steady state flow in accordance with Manning's Formula.

When a culvert operates with outlet control, the **average outlet velocity will be the discharge divided by the cross sectional area of the flow at the outlet.** This area is established by the indicated depth of flow which can be either:

1. Critical Depth (if there is no tailwater)

2. Tailwater Depths (if it lies above the critical depth and below the crown of the pipe).

3. Full Pipe Diameter or Rise of Arch or Elliptical Pipe (if the tailwater is above the crown of the pipe).

When considering small drainage structures, it can generally be assumed that a free outfall with no, or very low, tailwater exists.

V–04.10 Erosion Control

The NDDOT has adopted the general policy to provide some sort of erosion control when the outlet velocities are greater than 10 feet per second.

The following is a guide for erosion control at the outlet of culverts:

- Riprap is recommended only in extreme conditions. Most often the recommendation is to use temporary control measures such as listed below or other state-of-the-art products.

- Culverts with 30 in. diameter or greater, on slopes 3% and greater, should have Baffle Rings in addition to the riprap.

  These rings restrict the normal flow causing a hydraulic jump within the culvert, resulting in reducing the outlet velocity. The design and spacing of the rings are such that the culvert will flow full at design discharge. Under normal conditions the rings can reduce the outlet velocity by approximately 60%. See Standard Drawing D–714–13 for design details (Book of Standard Drawings).

■ Energy dissipaters such as Blocks, Sills, or other roughness elements used to impose exaggerated resistance to flow, may be required when the outlet conditions can't be controlled with the above measures.

In addition to those noted above the following materials are available for temporary protection to prevent the soil and grass seed from eroding away before the grass gets established:

- Mulch (Straw or Hay)
- Soil Retention Blanket (Wood, Straw, or Fiber Mats)
- Sediment Filters are used during construction as temporary control
  - Silt Fences
  - Bale Checks

  See Standard Drawing D–708–2 for design details.

Concrete Erosion Control Blankets can be used where it is necessary to provide Riprap protection within the Clear Zone of a roadway. Depending on the thickness of the Mats, an errant vehicle could traverse them whereas it could not with regular Riprap.

V–04.11 Culvert Location

The AASHTO " Highway Drainage Guidelines", mentioned at the beginning of this section, emphasizes the importance of the horizontal and vertical alignment of the culverts so they are sediment- free**.** The designer is encouraged to consult that document for a more in depth study of this item.

V–04.12 Standard Drawings

The following is a list of Standard Drawings that pertain to Small Drainage Structures:

Standard	Description
D–714–1	Reinforced Concrete Pipe Culverts and End Sections.
D–714–2	Reinforced Concrete Pipe Arch Culverts and End Sections
D–714–3	Reinforced Concrete Horizontal Elliptical Culverts and End Sections.
D–714–4	Corrugated Steel Pipe Culverts and End Sections
D–714–5	Corrugated Steel Pipe Arch Culverts and End Sections
D–714–6	Corrugated Aluminum Pipe Culvert and End Section (Round Pipe)
D–714–7	Corrugated Aluminum Pipe Arch Culverts and End Sections
D–714–13	Reinforced Concrete Pipe Baffle Rings
D–714–14	Corrugated Polyethylene Pipe
D–714–22	Concrete Pipe Ties

Appendix V–04 A

Drainage Studies - Procedural Guide

(Rural Design)

I. Collect Drainage Data

- aerial photos
- existing plans
- survey
- DTM (data terrain model- If available)
- USGS maps
- archive history of project area

II. Prepare Drainage Sketch (Existing Conditions & Drainage Patterns)

- details of existing drainage structures
- locate adjacent buildings and structures upstream and downstream
- drainage ditches
- upstream and downstream pipes
- approach pipes

III. Prepare Drainage Plan

- proposed grade line, office location alignment etc.
- locate proposed centerline and approach pipes
- delineate drainage areas to each centerline pipe

IV. Compute Discharge to Each Pipe

- select appropriate frequency
- measure drainage areas in acres
- determine watershed channel slope
- determine pipe slope and length
- set allowable headwater depth
- compute discharge
- complete hydraulic computations, see SFN 51828 (Appendix V–03 G)

V. Pinpoint Areas of Existing or Potential Drainage Problems

- refer to drainage history, district and local water resource district
- list of questions

VI. Field Inspection

- verify drainage splits, ditch blocks and watershed boundaries
- observe particular areas of interest, erosion, cattails, highwater marks etc.
- take ground photos

VII. Finalize Drainage Plan - Make Recommendations

- revise plan determined by field inspection
- select pipe size
- prepare recommendation report sheet - specify pipe size, outlet velocities, see SFN 51829 (Appendix V–03 G)
- prepare 100 year data for plan sheets, see SFN 52587 (Appendix V–03 G)
- coordinate with local water resource district for changes in the drainage pattern

VIII. Data and Information required for the Design Division Hydraulic Files.

- all correspondence
- delineation of watershed boundaries on contour maps (USGS maps) for all drainage structures
- drainage surveys
- hydraulic computations as stated on SFN 51828 HYDRAULICS COMPUTATION
- drainage structure recommendations as stated on SFN 51829 DRAINAGE STRUCTURE RECOMMENDATIONS - RURAL
- drainage data as stated on SFN 52587 DRAINAGE DATA and included on plan sheets